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G-Gran Sasso: an experiment for the terrestrial measurement of the Lense-Thirring effect by means of ring-lasers

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Abstract

The talk presents a proposal for a new experiment aimed to the detection of the gravito-magnetic Lense-Thirring effect at the surface of the Earth. The proposed technique uses a three-dimensional set of gyrolasers and exploits the anisotropic propagation of light in the gravitational field of a rotating mass. The experiment is planned to be built in the Gran Sasso National Laboratories in Italy and is based on an international collaboration among various Italian groups, the Technische Universität München and the Canterbury University in Christchurch (NZ).

1 Introduction

Until now the General Relativistic drag of the inertial frames in the field of a rotating mass (Lense-Thirring effect [1] [2]) has been experimentally verified only twice: by Ciufolini and collaborators [3] and by the Gravity Probe B (GP-B) experiment led by Francis Everitt [5]. In the former case the attained accuracy has been 10%; in the latter the accuracy has been 19%. In both cases the measurements were based on the material precession of angular momenta. The only ongoing further experiment is LARES, launched on February 13 2012 [4], whose objective is the measurement of the Lense-Thirring (LT) effect with the accuracy of a few %, possibly 1%.

Here I am presenting the recently proposed G-GranSasso experiment to test the terrestrial LT effect; the Principal Investigator is Angela Di Virgilio of the Pisa section of the Italian INFN. The proposal is presented by a collaboration among five universities in Italy plus the INFN and the Technische Universität München; a permanent consultancy exists with the Canterbury University in Christchurch (NZ). G-GranSasso will use light as a probe and will exploit the anisotropic propagation of light in the gravitational field of a rotating mass. A three-dimensional array of ring-lasers located in an underground terrestrial laboratory will measure the asymmetry evidencing various relativistic effects, including LT with the expected accuracy of 1%. The present sensitivity of

the best existing ring laser ¹ is approximately one order of magnitude above the threshold to be trespassed in order to measure LT; it is then reasonable to expect the right sensitivity to be attainable in a specially designed new instrument adopting the best technologies of the moment. The details of our proposal may be found in [6].

2 Light in axially symmetric space-times

A steadily rotating mass is surrounded by a space-time endowed with an axial symmetry around a time-like axis. Choosing a reference frame centered on the body and polar space coordinates the general line element of such a space-time is:

$$ds^2 = g_{00}dt^2 + g_{rr}dr^2 + g_{\theta\theta}d\theta^2 + g_{\phi\phi}d\phi^2 + 2g_{0\phi}dtd\phi. \quad (1)$$

In a terrestrial (then non-inertial) laboratory and up to the first Post Newtonian (PN) approximation keeping the angular momentum of the earth it is [6]:

$$\begin{aligned} g_{0\phi} &\simeq (2\frac{j}{r} - r^2\frac{\omega}{c} - 2\mu r\frac{\Omega_{\oplus}}{c}) \sin^2 \theta \\ g_{00} &\simeq 1 - 2\frac{\mu}{r} - \frac{\omega^2 r^2}{c^2} \sin^2 \theta \end{aligned} \quad (2)$$

In (2) a couple of shorthand symbols have been used:

$$\begin{aligned} \mu &= G\frac{M_{\oplus}}{c^2} \approx 4.4 \times 10^{-3} \text{ m} \\ j &= G\frac{J_{\oplus}}{c^3} = G\frac{\Omega_{\oplus}I_{\oplus}}{c^3} \approx 1.75 \times 10^{-2} \text{ m}^2 \end{aligned} \quad (3)$$

G is Newton's gravitational constant; \mathbf{J}_{\oplus} is the angular momentum of the earth and I_{\oplus} is its moment of inertia; Ω_{\oplus} is the angular velocity of the planet and ω is the absolute angular velocity of the apparatus (in practice it will coincide with Ω_{\oplus}).

Let us consider a ring laser made of an active cavity from which two light beams emerge in opposite directions. A number of mirrors (≥ 3) give rise to a closed loop in space, along which the two counter-propagating light beams move. It turns out that light takes different times to go round in clock or counter-clock sense; in a ring-laser the anisotropy shows up in the form of a beat frequency of standing waves [6]. The final frequency difference (the expected signal) is [6]:

$$\begin{aligned} \delta f &= 4\frac{A}{\lambda P}[\Omega_{\oplus} - 2\frac{\mu}{R}\Omega_{\oplus} \sin \theta \hat{\mathbf{u}}_{\theta} + \frac{GJ_{\oplus}}{c^2 R^3}(2 \cos \theta \hat{\mathbf{u}}_R + \sin \theta \hat{\mathbf{u}}_{\theta})] \cdot \hat{\mathbf{u}}_n \\ &= 4\frac{A}{\lambda P}[\Omega_{\oplus} + \Omega_g + \Omega_B] \cdot \hat{\mathbf{u}}_n \end{aligned} \quad (4)$$

The ring laser has been assumed to be contained in a plane; A is the area contoured by the light beams; P is the length of the loop; λ is the wavelength of the light of the laser; θ is the colatitude of the site; $\hat{\mathbf{u}}_n$ is the unit vector

¹It is G, located in Wettzell, Germany.

along the normal to the plane of the ring; $\hat{\mathbf{u}}_R$ is the radial unit vector; $\hat{\mathbf{u}}_\theta$ is the unit vector along the local meridian (towards increasing colatitudes); R is the radius of the earth or, to say better, the radial distance of the laboratory from the center of the earth.

Considering the orders of magnitude we see that $\Omega_\oplus \simeq 7.2 \times 10^{-5} \text{ s}^{-1}$ and $\Omega_G \sim \Omega_B \approx 10^{-9} \times \Omega_\oplus \approx 10^{-13} \text{ s}^{-1}$. These numbers set the goal to be attained in order to measure the properly general relativistic effects, i.e. the Ω_G and Ω_B "precession rates".

3 G-GranSasso

The proposal named G-GranSasso is to build a set of square ring lasers (not less than three) in a three-dimensional array, with a high enough sensitivity to reveal the general relativistic contributions and especially the LT effect. Two possible configurations are under analysis: a cubic concrete monument carrying six lasers on its faces; an octahedron made of three square loops. In the former case we would have a redundancy factor 2; the octahedral configuration instead lends the possibility to better control the geometry using resonating cavities (Fabry-Pérot interferometers) along the main diagonals.

In any case the side of the square loops would be 6 m long, giving a scale factor $S = 4A/\lambda P$ 50% higher than for G; the power of the laser should be 200 nW; the quality factor of the resonating cavities would be $Q = 3 \times 10^{12}$. The whole instrument would be located deeply under ground in the Gran Sasso National Laboratories in Italy; the reason of the underground laboratory choice is the screening from the surface mechanical noise. The objective is to measure the general relativistic "precessions" with an accuracy of the order of $\sim 1\%$.

First analyses and evaluations show that the LT effect could be revealed with the desired accuracy after a several months long integration time [6].

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